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A review of internal combustion engines applied to unmanned aerial vehicles

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Internal combustion engines constitute one of the two fundamental propulsion categories used in unmanned aerial vehicles (UAVs). This article analyzes the occurrence and application of individual types of internal combustion engines across unmanned platforms, with particular emphasis on their influence on aircraft performance and mission profiles. The advantages and limitations of specific propulsion system configurations are identified in the context of unmanned aviation, including factors such as energy efficiency, mass, structural complexity, endurance, and acoustic and thermal signatures. In addition, representative UAVs employing different types of internal combustion engines are presented, illustrating the practical implications of propulsion system selection in real-world operational applications.

Key words: *unmanned aerial vehicles (UAVs), internal combustion engines, aircraft propulsion systems, piston and turbine engines, endurance-oriented propulsion*

1. Introduction

The development of unmanned aerial vehicles (UAVs) is closely linked to the evolution of propulsion systems, as propulsion determines the key operational parameters of a platform, including endurance, range, service ceiling, airspeed, payload capacity, and overall reliability. In the early stages of UAV development – primarily focused on aerial targets and simple surveillance platforms – relatively uncomplicated piston engines adapted from light aviation or other small-engine applications predominated. These power plants were selected primarily for their favorable power-to-weight ratio and ease of integration. As the requirements of reconnaissance, surveillance, and later strike missions increased, greater emphasis was placed on cruise efficiency, stable operation over long duty cycles, and the ability to maintain performance across a wider range of altitudes and ambient temperatures.

In recent years, the rapid expansion of unmanned aerial vehicle applications in both civilian and military sectors has significantly increased the importance of propulsion system optimization. Modern UAVs are expected to perform increasingly demanding missions, including long-endurance intelligence, surveillance and reconnaissance (ISR), precision strike operations, cargo transport, border monitoring, environmental sensing, and autonomous cooperative missions. These operational requirements impose growing demands on propulsion systems for fuel efficiency, reliability, endurance, payload capability, reduced thermal and acoustic signatures, and operational flexibility. Simultaneously, recent research trends in UAV propulsion have increasingly focused on hybrid-electric architectures, heavy-fuel compatibility, advanced engine control systems and mission-oriented propulsion optimization.

Despite the dynamic development of electric propulsion in the micro- and mini-UAV classes, the energy density limitations of batteries mean that liquid fuels remain the dominant energy carrier for medium- and large-scale platforms. Consequently, internal combustion propulsion systems continue to form the backbone of UAVs requiring multi-hour endurance and the capability to carry significant payloads. In parallel, turbine-based propulsion systems have been developed for high-speed platforms, for which operation in flight regimes unattainable for conventional propeller-driven configurations is a primary requirement. In recent years, increasing attention has also been paid to hybrid propulsion architectures, in which an internal combustion engine serves as an onboard energy source while electric motors provide propulsion.

From a systems perspective, internal combustion engines used in UAVs can be classified into three main groups: spark-ignition piston engines, compression-ignition piston engines, and gas turbine engines. Two-stroke spark-ignition engines are employed primarily in lightweight platforms, where a high power-to-weight ratio and mechanical simplicity are critical, often at the expense of higher specific fuel consumption and less favorable acoustic characteristics. Four-stroke spark-ignition engines dominate many tactical UAVs and MALE-class systems, where efficiency during prolonged cruise and stable operation in multi-hour missions is essential. Compression-ignition and heavy-fuel engines are being developed to further improve efficiency and enable fuel commonality in military applications; however, their implementation requires advanced fuel-injection control, turbocharging, and design solutions that ensure reliable cold- and high-altitude-starting. Turbine propulsion systems, in turn, represent a natural choice for high-speed UAVs, where flight dynamics and a high thrust-to-weight ratio take precedence over maximum fuel economy.

The purpose of this review article is to provide an overview of current knowledge and development of internal combustion propulsion systems for unmanned aerial vehicles, with particular focus on the relationships among propulsion system characteristics, operational effectiveness, mission requirements, and platform integration limitations.

This review contributes to the existing body of research by providing a comprehensive evaluation and comparison of internal combustion propulsion technologies across different UAV categories and operational applications. In contrast to many previously published studies concentrating on individual engine types or selected groups of unmanned platforms, the present work combines the historical evolution of UAV propulsion, propulsion system classification, operational properties, representative aircraft examples, and mission-oriented performance analysis within a single coherent framework. Special emphasis is placed on the interdependence between propulsion architecture, endurance, fuel economy, operational altitude, payload capability, detectability, and integration-related complexity. Additionally, the review highlights current technological developments and outlines prospective trends in UAV propulsion, including hybrid propulsion concepts, heavy-fuel engines, and low-observability propulsion solutions.

2. History of UAV propulsion systems

The earliest recorded instance of unmanned aerial vehicles is commonly associated with the aerial attack on Venice on 12 July 1849 by Austro-Hungarian forces. The means of attack consisted of approximately 200 small hot-air balloons carrying explosive charges. Although these aerostats may be regarded as the earliest unmanned aerial systems, they were extremely simple constructs, devoid of propulsion and any form of control [39]. The first unmanned aerial vehicle equipped with its own propulsion system did not appear until World War I. At that time, as manned aviation was rapidly developing, the first concepts of crewless aircraft began to emerge. Great Britain assumed a leading role in this field, where several independent radio-controlled fixed-wing projects were developed under the Aerial Target program, using a control system designed by the RFC's Experimental Works, led by Archibald Low. After three years of research, a prototype fixed-wing UAV conducted its first unmanned flight on 21 March 1917. Propulsion was provided by an air-cooled, two-cylinder ABC Gnat engine with a displacement of 2.3 dm^3, producing 34 kW of power [45, 55].

A similar line of development was pursued by Elmer Sperry, who, in cooperation with Peter Hewitt, undertook the conversion of the Curtiss N-9 seaplane into an unmanned aircraft. As in the original manned version, the UAV was powered by a water-cooled Wright-Hisso A V8 engine, structurally derived from the Hispano-Suiza 8. The powerplant, with a displacement of 11.8 dm^3, delivered a maximum power output of 110 kW [4, 45]. Further work by Sperry, this time in collaboration with Charles Kettering and the Dayton-Wright Airplane Company, led to the development of the Kettering Bug unmanned attack aircraft. In contrast to earlier designs, the propulsion system represented a significant departure. The primary engine selection criteria for this precursor of modern cruise missiles were simplicity of construction, low production cost, and a high power-to-weight ratio. Consequently, a two-stroke DePalma V4 engine manufactured by the Ford Motor Company was selected, delivering 28 kW of power, sufficient to propel the relatively small airframe [47, 58].

Another breakthrough in UAV propulsion occurred in 1921 with the development of the RAE Larynx prototype, the first unmanned aircraft powered by a radial engine. The propulsion system was a seven-cylinder, air-cooled Armstrong Siddeley Lynx IV radial engine. With a displacement of 12.4 dm^3, it produced 150 kW of power [64, 83]. The first inline engine applied to unmanned aircraft followed in 1933, when the de Havilland Gipsy Major was used to power the de Havilland DH.82 Queen Bee, an unmanned variant of the de Havilland DH.82 Tiger Moth. This air-cooled inline four-cylinder engine, with a displacement of 6.1 dm^3, generated a maximum power output of 96 kW [25, 26]. Another important milestone in the development of unmanned aviation was the establishment of Reginald Denny Industries in 1935, later transformed into the Radioplane Company – the first dedicated drone manufacturer in history. Although its OQ-2 and OQ-3 UAVs became the first unmanned aircraft to be mass-produced, they did not introduce significant innovations in propulsion, which remained based on two-cylinder spark-ignition engines.

A further major advance occurred with the German V-1 research programme, which resulted in the first mass-produced cruise missile, the Fieseler Fi 103. This system was also the first unmanned aerial vehicle powered by an air-breathing jet engine. The Argus As 014 pulsejet engine produced 2.7 kN of thrust, accelerating the vehicle to approximately 640 km/h. Following the end of World War II, jet propulsion technology and its aviation applications developed rapidly, with corresponding effects in the unmanned domain. In 1948, the U.S. Air Force awarded Ryan Aeronautical Company a contract to develop and manufacture the first turbojet-powered unmanned aircraft. The first flight of the XQ-2 Firebee prototype, powered by a Continental J69-T-19B engine, took place in 1951, with the engine producing a maximum thrust of 4.7 kN. In 1960, the BQM-34A production variant entered service, equipped with the Continental J69-T-29A engine delivering up to 7.6 kN of thrust, enabling maximum speeds of approximately 1,110 km/h [26, 59]. Similar developments occurred on the opposite side of the Iron Curtain. Production of the first Soviet turbojet-powered UAV, the Lavochkin La-17, began in 1954. Propulsion was provided by the Mikulin RD-9BK engine, a simplified derivative of the powerplant used in the MiG-19 fighter aircraft. From that point onward, unmanned aviation increasingly shifted to jet propulsion, reflecting the broader aviation trend of the era toward ever-higher flight speeds. This trajectory culminated in the development of the first unmanned aircraft powered by a ramjet engine. On 5 March 1966, the Lockheed D-21, equipped with the RJ43-20S4 ramjet engine, conducted its first test flight.

During the 1970s, unmanned aviation experienced a return to smaller platforms intended for tactical reconnaissance missions. Due to the operational characteristics of such missions, piston engines once again became the preferred propulsion solution. Israel emerged as a leading center of research and development in this field, particularly through the state-owned Israeli Aircraft Industries. Between 1970 and 1990, three major UAV programmes of this type were developed: the Tadiran Mastiff, IAI Scout, and RQ-2 Pioneer [17]. During the same period, rotary engines entered the unmanned aviation domain. The BTT3 Banshee, developed in the early 1980s by Target Technology Ltd., is generally recognized as the first UAV to employ a rotary engine. Early versions of the fixed-wing platform were powered by a two-stroke, two-cylinder Normalair-Garrett engine rated at 19 kW. Subsequent development led to the Banshee Whirlwind variant, which used a Norton P73 Wankel rotary engine producing 28 kW. Rotary engines have since remained present in the UAV market, finding application in several projects over the following four decades [66].

A new avenue of development was opened by tests initiated in the United States in 2004. Until that time, all piston-engine-powered UAVs, regardless of engine type, relied on gasoline as their primary fuel. In 2004, however, the U.S. Air Force initiated efforts to employ compression-ignition engines in unmanned aerial vehicles. The key motivation was a significant simplification of logistics: fuel supplied to ground vehicles could also power the aerial component. The RQ-5 Hunter UAV, previously powered by two Moto Guzzi spark-ignition engines, was selected for the pilot program. In the MQ-5 Hunter variant, propulsion was changed to two Mercedes HFE Diesel inline three-cylinder engines. Although the logistical advantages were substantial, compression-ignition engines have not been widely adopted in unmanned aviation [16, 37].

The most recent major transformation in UAV propulsion has been the widespread adoption of electric propulsion systems. Achieving this shift required sufficient technological maturity, particularly in electrical energy storage and electronic component miniaturization. Early attempts to employ electric propulsion in unmanned aircraft date back to the 1950s, primarily in experimental platforms. A decisive breakthrough occurred in the 1990s with the development of brushless DC motors, advances in onboard electronics miniaturization, and the introduction of more efficient power controllers. The widespread availability of lithium-polymer and lithium-ion batteries after 2000 enabled a substantial increase in the energy density of onboard power systems. As a result, electric propulsion became viable for small-scale unmanned aerial vehicles. Owing to its mechanical simplicity, low cost, and ease of operation, electric propulsion remains the most prevalent propulsion type in micro- and mini-class UAVs to this day.

3. Engine types

3.1. Two-stroke spark-ignition engines

Two-stroke spark-ignition engines constitute an important group of propulsion sources for small- and medium-class unmanned aerial vehicles, particularly in applications where a high power-to-weight ratio and the structural simplicity of the propulsion system are prioritized. In a two-stroke engine, the complete working cycle is accomplished within a single crankshaft revolution, which, from a kinematic standpoint, enables relatively high power density with fewer mechanical components than in four-stroke units. From the perspective of UAV airframe integration, this translates into a favorable propulsion system mass and potentially reduced installation volume requirements, which is especially important in designs with limited internal fuselage space and stringent maximum take-off mass constraints. Two-stroke piston engines are therefore particularly attractive in UAV classes with a maximum take-off mass below approximately 100 kg, where the trade-off between performance, cost, and system simplicity is critical [24].

At the same time, the specific characteristics of the charge-exchange process in two-stroke engines (scavenging), as well as the typical lubrication solutions employed, impose several operational limitations. The most significant of these include elevated emissions of toxic exhaust components, high sensitivity to intake system operating conditions, and less favorable acoustic characteristics compared to four-stroke engines. In UAV applications, these factors are relevant not only from an environmental standpoint, but also due to increased acoustic detectability – particularly in military missions – and the dynamic loading of the airframe structure resulting from higher vibration amplitudes. Furthermore, conventional carburetor-based fuel delivery systems may degrade the mixture with increasing flight altitude, increasing the risk of power loss and incomplete combustion. One approach to mitigating this effect involves using fuel injection systems and more advanced mixture control strategies that vary with ambient conditions [24, 48].

From a systems-level perspective, it should be emphasized that the advantage of two-stroke engines in terms of specific power does not necessarily translate into superior mission-level energy efficiency. In endurance-oriented missions, specific fuel consumption and the stability of operating parameters over a wide range of loads are of paramount importance. Despite their favorable mass characteristics, two-stroke engines may require a higher fuel mass flow to deliver a comparable amount of useful shaft energy under cruise conditions, thereby reducing the overall benefit associated with engine mass reduction. For this reason, in many modern UAV classes, a gradual shift can be observed in which two-stroke engines are increasingly confined to platforms that prioritize short-duration flight, low acquisition cost, operational simplicity, and ease of maintenance over maximum endurance.

The literature on UAV propulsion systems indicates that the RQ-2 Pioneer (Fig. 1) platform employed a spark-ignition, two-stroke, two-cylinder piston engine manufactured by Fichtel & Sachs, installed in a pusher propeller configuration. The engine features a horizontally opposed layout and delivers approximately 20 kW of power. This propulsion system was selected for its favorable power-to-weight ratio and ease of integration into a short-range reconnaissance UAV [24, 57].

Fig. 1. RQ-2 Pioneer [57]

Another example of a two-stroke propulsion application is the Sperwer A/B unmanned aerial vehicle, which is equipped with a spark-ignition piston engine operating on the two-stroke cycle – the Bombardier-Rotax 582/562UL [12] (Fig. 2).

Fig. 2. Engine Rotax 582/562UL [12]

Technical sources emphasize the use of gasoline-class fuel, consistent with the operational practice for small spark-ignition engines in UAVs of this category. Such a propulsion choice aligns with the requirements of medium-mass tactical UAVs, providing relatively high specific power at moderate system complexity, at the expense of higher specific fuel consumption compared to four-stroke or heavy-fuel engines [81].

3.2. Four-stroke spark-ignition engines

Four-stroke spark-ignition engines are employed in UAVs primarily in applications where higher cruise efficiency, increased operational durability, and improved controllability of operating parameters over a wide load range are critical. Unlike two-stroke units, the four-stroke engine completes its working cycle over two crankshaft revolutions, with charge exchange controlled by a valve train, enabling more precise shaping of the intake and exhaust processes. In UAV applications, this translates into more stable operation during long-endurance missions, where low specific fuel consumption, repeatable performance, and relatively long maintenance intervals are essential.

The literature on propulsion system selection as a function of UAV mass indicates that four-stroke engines are particularly common in platforms with a maximum take-off mass exceeding approximately 50 kg, as they offer a favorable compromise between fuel economy and reliability, despite their higher mass and more complex mechanical architecture compared to two-stroke engines. Additional advantages include a dedicated lubrication system that eliminates the need for fuel oil premixing and reduces oil combustion emissions. Consequently, four-stroke engines are better suited to long-duration operations, where maintenance predictability and the mitigation of performance degradation over time are key considerations [24].

Conversely, the application of four-stroke engines in UAVs necessitates a deliberate approach to mechanical and thermal integration. The greater number of moving components, the inclusion of a valve train, and often more elaborate cooling and fuel supply systems increase overall mass and system complexity. This may require reinforcement of the engine mounting structure, careful consideration of vibration isolation, and the provision of stable cooling conditions during prolonged low-airspeed flight. An additional issue is susceptibility to intake system icing in carbureted configurations, as well as the need to ensure mixture control as a function of altitude, ambient temperature, and pressure. In many applications, these challenges are addressed through the use of fuel injection systems and turbocharging, which help to maintain power at altitude and improve operational flexibility under varying mission conditions [24].

In practice, four-stroke spark-ignition engines are widely represented in the MALE class, as well as in tactical and logistical platforms where endurance and payload capability must be achieved within reasonable operating costs. From the standpoint of acoustic and thermal detectability, four-stroke engines often offer a more favorable signature than two-stroke units at comparable power levels; however, actual detectability depends on a range of system-level factors, including propeller characteristics, exhaust attenuation, thermal insulation, and mission-specific operating regimes.

One of the most recognizable UAVs with a four-stroke propulsion system is the MQ-1 Predator, primarily employed in military missions. The MQ-1 is powered by a four-cylinder Rotax 914F engine (Fig. 3) rated at 115 hp. The platform is used for medium-range missions with an operational radius of up to 1,200 km, with its primary roles including reconnaissance and precision strikes using onboard weaponry [24, 31, 52].

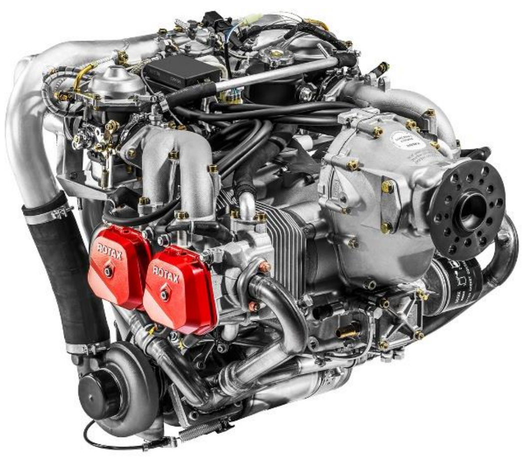

Fig. 3. Engine Rotax 914F [31]

Another example is the Bayraktar TB2, designed and manufactured in Turkey, which is equipped with a four-stroke Rotax 912 engine [81]. The Bayraktar TB2 is a MALE-class tactical UAV intended for intelligence, surveillance, and reconnaissance missions, as well as target acquisition and designation using an electro-optical payload that includes a laser rangefinder. In a typical operational profile, the platform conducts long-duration area surveillance, identifies and tracks targets, and transmits near-real-time data to a ground control station, thereby supporting tactical-level decision-making. In its armed configuration, the TB2 is also employed for limited-scale precision-strike missions using lightweight guided munitions carried on underwing hardpoints, combining ISR with strike capabilities.

Another configuration is the RQ-5 Hunter (Fig. 4), equipped with two four-stroke, two-cylinder, spark-ignition engines manufactured by Moto Guzzi, delivering a total power output of approximately 100 kW [24]. The RQ-5 Hunter is a UAV primarily intended for reconnaissance, surveillance, and target designation in support of ground forces. In operational use, the platform served as a real-time imagery source, assisting tactical commanders with situational assessment, monitoring adversary activity, and surveillance of selected areas and lines of communication. The system was employed in long-endurance observation missions, including expeditionary operations. A particularly significant and frequently emphasized role of the Hunter was target acquisition and artillery fire correction. In this mission profile, the UAV provided continuous updates on target position and movement, enabling battle damage assessment and shortening the "detect-decide-engage" cycle in land operations [11].

Fig. 4. RQ-5 Hunter [11]

Four-stroke spark-ignition piston engines in UAVs are therefore primarily used on platforms that require high cruise efficiency, stable operation during long-endurance missions, and enhanced reliability. Compared to two-stroke units, they generally offer lower specific fuel consumption, improved combustion control, and reduced vibration amplitudes, at the expense of increased mass and greater mechanical complexity. As a result, they dominate in tactical fixed-wing UAVs and MALE-class systems, where endurance and operational predictability of the propulsion system are the primary design drivers.

3.3. Compression-ignition engines

Compression-ignition (CI) engines in UAVs are developed and implemented primarily in response to two major categories of requirements:

- increased energy efficiency in long-endurance missions
- fuel logistics commonality in military and specialized applications.

The combustion process in CI engines is based on the auto-ignition of the fuel–air mixture, achieved by compressing the intake air to a pressure and temperature sufficient to initiate ignition, thereby eliminating the need for spark ignition. This mechanism, however, requires highly precise fuel injection and accurate control of the combustion process. Under typical UAV mission profiles, characterized by extended cruise segments and steady-state operating points, CI engines can offer a significant advantage through lower specific fuel consumption, which directly translates into increased endurance or a higher useful payload for a given onboard fuel mass.

From the perspective of operational safety and ground handling, heavy fuels generally exhibit lower volatility than gasoline, which may reduce fire hazards during maintenance operations and emergency situations. For military users, a particularly important argument is the ability to power multiple systems with a single fuel class (e.g., JP-8 or Jet A), thereby simplifying supply chains in expeditionary operations. Consequently, in the literature and in review studies on UAV propulsion systems, heavy-fuel engines are frequently associated with platforms intended for reconnaissance-strike roles and long-duration patrol missions [81].

These benefits, however, are achieved at the cost of substantial design and integration challenges. Compared to spark-ignition engines, CI units typically operate at higher peak in-cylinder pressures, resulting in increased mechanical loads and, consequently, potentially higher component mass or the need for advanced materials and structural solutions to ensure adequate strength. In addition, the CI combustion process is strongly dependent on the quality of fuel atomization and air-fuel mixing, which, under high-altitude flight conditions characterized by low air density and low ambient temperatures, may degrade ignition stability and lead to starting difficulties or unstable operation at low temperatures. These issues are sufficiently critical that studies of heavy-fuel propulsion emphasize technical barriers related to combustion stability, reliable ignition under adverse conditions, and the need for auxiliary systems to support engine start-up and sustained operation [70].

From a systems-level perspective, the use of a CI engine also affects the overall UAV architecture. Such engines often require advanced fuel injection control systems, effective boosting solutions to maintain power at altitude, and careful thermal management. These requirements influence mass, system complexity, and life-cycle costs; therefore, selecting CI propulsion is most justified in applications where the efficiency gains and heavy-fuel logistics advantages outweigh the increased integration complexity.

A 2023 review study [81] identifies several representative UAV platforms employing heavy-fuel propulsion systems. Among them is the MQ-1C Gray Eagle, for which the compilation reports the use of an HFE-class engine rated at approximately 180 hp, capable of operating on diesel fuel as well as aviation jet fuels, with reported endurance of approximately 42 hours and a payload capacity of 227 kg. The same review includes the ScanEagle 2 UAV (Fig. 5), equipped with a piston propulsion system adapted to heavy fuels such as JP-5 or JP-8, with reported endurance of 20 to 28 hours and a payload capacity of 5 kg [44]. The authors interpret this example as indicative of the trend toward fuel commonality even in smaller UAV systems. In addition, the CH-4 platform is cited as employing a propulsion unit described as an HFE engine operating on heavy fuel, with reported endurance of approximately 30 hours and a payload capacity of 115 kg, confirming the adoption of the heavy-fuel concept beyond Western UAV systems.

In summary, compression-ignition engines represent a propulsion solution for UAVs that maximizes the effectiveness of long-endurance missions and simplifies fuel logistics. However, their successful implementation requires a high level of design maturity in combustion control, boosting, cold- and high-altitude-start capability, and the mechanical and thermal integration of the entire propulsion system [64].

Fig. 5. ScanEagle 2 [44]

3.4. Rotary piston engines (Wankel engines)

The rotary piston engine, commonly referred to as the Wankel engine, was developed by Felix Wankel in the 1950s as an alternative to conventional reciprocating piston engines. Its design is based on the rotation of a triangular rotor within an epitrochoid chamber, eliminating the standard crankshaft mechanism, valves, and most of the moving components typical of four-stroke piston engines. While Wankel engines did not achieve dominance in automotive applications, their unique design characteristics make them particularly attractive for unmanned aerial vehicle applications.

A primary limitation of conventional piston engines is the need to convert reciprocating motion into rotational motion. In Wankel engines, this conversion is unnecessary, reducing parts and simplifying the overall engine structure. The reduced component count translates into lower mass and smaller dimensions. In aviation applications, the most significant advantages of rotary engines include a high power-to-weight ratio, relatively low total engine mass, and reduced vibration levels compared to conventional piston engines. However, their use in UAVs also entails drawbacks, including lower thermal efficiency, higher emissions, and accelerated component wear. Rotary piston engines are most commonly used in medium-sized UAVs intended for tactical operations, where electric propulsion is insufficient in power and energy density, while conventional piston engines may be too heavy for relatively lightweight airframes [1, 17, 49].

Representative applications of rotary piston engines in UAVs include:

– Hermes 450 (Fig. 6) – An Israeli medium-range, multirole UAV developed in the mid-1990s by Elbit Systems. The airframe, in a characteristic parasol-wing configuration, is powered by a UEL AR801 engine producing 40 kW. Post-2008 production units, designated Hermes 450W, were equipped with the upgraded UEL AR902(W) engine rated at 49 kW. The primary advantage of this UAV is its long endurance relative to other platforms in its class, achieving up to 17 hours, or even 30 hours in the Hermes 450LE variant. The program has been highly successful in export markets, with units delivered to the armed forces of multiple countries [7, 23, 30, 78].

Fig. 6. Elbit Hermes 450 [7]

– AAI RQ-7 Shadow – The most widely produced UAV with a rotary piston engine. Since its market introduction in 2002, over 500 units have been delivered, predominantly to the U.S. Army. The twin-boom airframe is powered by an AR741-1101 engine (Fig. 7) producing 28 kW, driving a two-blade pusher propeller. Designed for short-range reconnaissance, the UAV can fly for 6 hours at 130 km/h. Missions are supported by the onboard POP300 electro-optical payload produced by Israel Aerospace Industries, which includes both a daylight camera and an infrared sensor [2, 31, 36, 77].

Fig. 7. AR741-1101 engine [2]

- Nostromo Yarará – The first serially produced UAV designed in South America, introduced in 2006 by the Argentine company Nostromo Defensa. Its propulsion system consists of an air-cooled Sonic 35 rotary piston engine, the first rotary unit designed to operate on JP-8, the standard turbine fuel for NATO military forces. The engine produces 5.9 kW at the three-blade pusher propeller. With a cruise speed of 115 km/h, the maximum flight endurance is six hours [9].
- Schiebel Camcopter S-100 – An Austrian-produced rotary-engine UAV helicopter, introduced in 2005 to partially replace manned helicopters aboard naval vessels. The UAV, with a maximum take-off mass of 200 kg, is powered by a Schiebel S1 engine rated at 41 kW. Since 2012, an upgraded S2 engine version has been offered, compatible with JP-5, Jet A-1, and JP-8 fuels. The 57 L internal fuel capacity enables a 6-hour flight, which can be extended to 10 hours with additional external fuel tanks. The Camcopter S-100 has gained international recognition, with units delivered to military and civilian institutions in 29 countries [6, 69].

3.5. Pulsejet engines

Pulsejet engines constitute a distinct class of jet propulsion systems, characterized by mechanical simplicity and the absence of complex components such as compressors or turbines. Their operation is based on cyclic combustion of a fuel–air mixture within a combustion chamber, with or without valves, generating periodic bursts of hot gases that produce thrust in an impulsive manner. This design results in extremely low production costs, while the lack of rotating components makes the engine tolerant to ingestion of small debris and particulate matter, reducing the risk of damage and simplifying maintenance [62, 65].

The efficiency of pulsejet engines is generally very low, which limits their application to cases where simplicity and low manufacturing cost outweigh propulsion efficiency. Typically, these engines are used in expendable UAVs, such as strike drones or target drones, where the one-time nature of the mission renders high engine efficiency unnecessary, and the production cost of propulsion units is a critical factor. Historically, pulsejets were also employed before the development of reliable turbojet engines [62, 65].

Since the introduction of the first pulsejet-powered UAV, the German V-1, several unmanned aircraft have employed this type of propulsion:

- TD2D Katydid – An American target drone introduced by the U.S. Navy in 1942. To achieve higher maximum speeds that better simulate contemporary manned combat aircraft, a pulsejet engine was selected over the piston engines commonly used at the time. The McDonnell XPJ40-MD-2 engine was developed specifically for this application, generating 2.9 kN of thrust. The UAV could reach 400 km/h, compared to 200–220 km/h for piston-engine drones of the same era. Fuel capacity allowed for a 40-minute flight [56].
- Aviolanda AT-21 – A target UAV developed in 1955 by Aviolanda, becoming the first Dutch UAV produced in series. The aircraft, in a conventional layout, was powered by a SNECMA AS-11 Écrevisse pulsejet producing 0.85 kN of thrust. Maximum speed reached 346 km/h, while a cruise speed of 285 km/h allowed a 70-minute flight on 120 L of fuel [21].
- Scitor-D (Fig. 8) – A UAV presented in March 2024 by Wave Engine Corp. as a technology demonstrator for the modern J-1 pulsejet engine. The primary advantages of this propulsion unit are its extreme mechanical simplicity, absence of moving parts, and wide range of compatible fuels. According to the manufacturer, the engine can operate on gasoline, aviation fuels such as JET-A and JP-8, and E85 biofuel. The unit has a mass of 7.5 kg and generates up to 0.24 kN of thrust, suitable for small UAVs. Additionally, the company is developing the K-1 engine, intended for larger airframes, capable of producing approximately 1 kN of thrust [22, 80, 82].

Fig. 8. Wave Engine Corp. Scitor-D [22]

3.6. Turbojet engines

Turbojet engines generate thrust by accelerating a stream of exhaust gases produced by the combustion of aviation fuel in the combustion chamber and subsequent expansion through the turbine and exhaust nozzle. Compared to conventional piston engines, they are characterized by a very high thrust-to-weight ratio, a mechanically simple architecture, and the capability to operate over a wide range of altitudes and flight speeds. These features make turbojet engines suitable for unmanned aerial vehicles intended for high-speed, high-altitude flight [1, 53].

The principal disadvantage of turbojet engines is their high specific fuel consumption, which significantly limits aircraft endurance. For this reason, turbojets are most commonly employed in strike UAVs and aerial target drones. Both categories share a requirement for high flight speed combined with relatively short mission durations, typically not exceeding several hours. In addition, the expendable or single-use nature of such missions favors propulsion systems that are inexpensive and structurally uncomplicated–criteria that turbojet engines satisfy well [1, 17].

In reconnaissance UAV applications, turbojet engines are used far less frequently and are typically replaced by turbofan engines. This is due not only to turbojet high fuel consumption but also to their elevated acoustic output and infrared signature, which substantially increase platform detectability. The application of turbojet engines in smaller tactical-class UAVs is also problematic, as most such platforms are designed to operate at relatively low airspeeds, typically between 50 and 150 km/h. At these speeds, turbojet efficiency is markedly lower than at higher velocities, rendering their use technically and operationally unjustified [1, 17].

Representative examples of UAVs powered by turbojet engines include:

- Ryan BQM-34 Firebee – An aerial target drone produced by the Ryan Aeronautical Company starting in 1960. It is powered by a Continental J69-T-29A turbojet engine delivering a maximum thrust of 7.6 kN, enabling the aircraft to reach speeds of up to 1,110 km/h. Launch is performed either from a ground-based launcher using a rocket-assisted takeoff system or airborne from pylons mounted on specially modified Lockheed DC-130 aircraft. At a cruise speed of approximately 1010 km/h, the onboard fuel supply supports a flight endurance of about 75 minutes. More than 6,500 Firebee units were produced, with some variants remaining in service to this day [59].
- Nord Aviation CT20 – A French target drone developed in 1957 and powered by a Turbomeca Marboré II turbojet engine generating 3.9 kN of thrust. Launch was conducted from a ramp using two auxiliary rocket boosters. The UAV could sustain a maximum flight duration of approximately 55 minutes and reach speeds of up to 900 km/h. Produced in around 1500 units, the CT20 served as one of NATO's primary aerial target systems during the second half of the 20th century [13, 74].
- Shahed-238 (Fig. 9) – An Iranian strike UAV introduced in 2023. The platform, carrying a 50-kg warhead, is powered by a Toloue-10 turbojet engine, a derivative of the Czech PBS TJ-100 (Fig. 10). The engine produces up to 1.5 kN of thrust, enabling a maximum airspeed of approximately 600 km/h. Flight endurance is estimated at around 2 hours. Compared to the piston-engine-powered Shahed-136, the adoption of turbojet propulsion increased maximum speed by more than 400 km/h, significantly reducing transit time over hostile territory and complicating air defense countermeasures [3, 71, 73].

Fig. 9. Shahed-238 [73]

- UJ-23 Topaz – A multirole UAV produced by UKRJET since 2023, featuring forward-swept wings and a V-tail configuration. The platform is powered by a turbojet engine, although specific engine type and parameters remain classified. Publicly available data indicate a maximum speed of approximately 800 km/h and a maximum flight time of about 20 minutes. A derivative version, the UJ-25 Skyline, has been developed as a loitering munition equipped with a 10-kg warhead [79].

Fig. 10. PBS TJ-100 turbojet engine [3]

3.7. Turboprop engines

A turboprop engine is a type of gas turbine propulsion system in which most of the fuel's chemical energy is converted into mechanical power to drive a propeller, rather than directly generating thrust from the exhaust stream. Ambient air is drawn into the engine and compressed in a compressor, then directed into the combustion chamber, where fuel and air are burned. The hot exhaust gases expand through a turbine, which extracts mechanical energy. In a turboprop engine, most of the turbine's power is transmitted to a driveshaft and then, through a reduction gearbox, to the propeller. The gearbox reduces rotational speed while increasing torque, allowing the propeller to rotate at an optimal speed below the turbine shaft speed [1, 18].

The primary advantage of turboprop engines is their low fuel consumption during flights at moderate speeds. Within the typical speed range of 200–450 km/h, turboprop propulsion offers the highest fuel efficiency among all available propulsion types. This characteristic makes turboprops the preferred choice for medium- and long-range reconnaissance UAVs, where maximum speed is secondary to extended endurance [18, 84].

Turboprop propulsion, however, imposes limitations. Maximum airspeed is considerably lower than that achievable with turbojet or turbofan engines. Due to the propeller's operational characteristics, turboprop UAVs generally do not exceed speeds of approximately 500 km/h. They are also typically constrained to medium altitudes, generally below 30–35,000 ft. Consequently, turboprops occupy a performance niche between piston and jet engines: they operate faster than piston-powered UAVs but slower than jet-powered systems, and they achieve peak efficiency at altitudes too high for piston engines but below optimal turbofan altitudes [18, 84].

Representative UAVs employing turboprop propulsion include:

- MQ-9A Reaper (Fig. 11) – A U.S. MALE-class (Medium Altitude, Long Endurance) UAV developed by General Atomics Aeronautical Systems in 2001 as an evolution of the MQ-1 Predator. The platform is designed for long-endurance flights, advanced reconnaissance, and precision strike missions over large areas at medium-to-high altitudes. Propulsion is provided by a Honeywell TPE331-10GD turboprop engine (Fig. 12) delivering up to 670 kW to a pusher propeller. The aircraft achieves a maximum speed of 480 km/h, while endurance reaches approximately 27 hours (up to 34 hours in the MQ-9 ER variant). Coupled with advanced sensor suites, including radar, electro-optical payloads, and electronic warfare modules, the MQ-9 represents a versatile and highly capable system for modern operations [42, 75, 85].

Fig. 11. MQ-9A Reaper [75]

- Bayraktar Akinci – A Turkish HALE-class (High Altitude, Long Endurance) multirole UAV developed in 2019 by Baykar Makina. The platform uses two turboprop engines, with specific models depending on the variant: AI-450T (340 kW each) in Version A, PT6A-135A (560 kW) in Version B, and Motor Sich MS-500V (630 kW) in Version C. The UAV has an operational ceiling of 30,000 ft and a cruise speed of 280 km/h. Onboard fuel allows for a 25-hour flight with a maximum range of 7500 km. Eight underwing hardpoints enable the deployment of a wide range of armaments, with a total payload of up to 1500 kg [19, 38].

Fig. 12. Honeywell TPE331-10GD [42]

- IAI Heron TP – An Israeli HALE-class UAV introduced in 2007 by Israel Aerospace Industries. The aircraft features a twin-boom configuration and is powered by a Pratt & Whitney Canada PT6A-67A turboprop engine producing 883 kW and driving a four-blade pusher propeller. The platform has an operational ceiling of 41,000 ft and endurance exceeding 30 hours, positioning it among the leading long-range reconnaissance UAVs globally [8, 43].
- TAI Turna – A delta-winged target drone introduced in 2001 by Turkish Aerospace Industries. The original version was powered by a rotary piston engine (AR741), while a 2008 upgrade introduced a turboprop engine, the TEI-TP-1X, rated at 28 kW. The UAV reaches a maximum speed of 330 km/h and has an endurance of up to 90 minutes. The use of turboprop propulsion in a small, low-altitude UAV makes this a unique design within its class [8, 46, 54, 77].

3.8. Turboshaft engines

Turboshaft engines belong to the class of turbine powerplants designed to deliver mechanical power to an output shaft rather than producing direct thrust. Essentially, they are gas turbines adapted for continuous rotational power output, which can then be utilized for mechanical propulsion. Unlike turboprop engines, turboshafts do not include a gearbox or propeller, although the operating principle of the core engine is the same. In aviation applications, turboshaft engines are often converted into turboprops by adding a reduction gearbox and a propeller. A notable example is the Rolls-Royce M250 turboshaft engine, which was adapted for unmanned aviation into a turboprop unit used in demonstrators such as the BAE Mantis [61, 84].

Turboshaft engines are primarily used in rotorcraft UAVs, powering the main rotor. They are also employed in hybrid UAV propulsion systems, where the turboshaft generates electrical power that drives electric motors connected to rotors or propellers [61, 84].

Representative UAVs employing turboshaft technology include:

- Bell Eagle Eye – A VTOL UAV developed in the late 1990s for the U.S. Navy VT-UAV program. A Pratt & Whitney Canada PW207D turboshaft engine housed in the fuselage transmitted power via a gearbox to two rotors mounted in movable wingtip pods. The orientation of these pods controlled the flight mode: in vertical position, the rotors enabled VTOL operation, and in horizontal position, they provided forward flight. The program was ultimately discontinued following a prototype accident in 2006 [32, 60].
- Boeing A160T Hummingbird (Fig. 13) – A UAV helicopter first flown in 2007, designed for extended endurance and long-range operations. Early A160 variants used Subaru piston engines, but in 2007, the platform was upgraded with Pratt & Whitney Canada PW207D turboshaft engines (Fig. 14). During testing, the UAV achieved 20 hours of endurance and over 4,000 km of range. The project also featured an advanced autonomous flight control system. Despite technical achievements, the program was suspended in December 2012 [5, 27, 41].

Fig. 13. Boeing A160T Hummingbird [27]

- MQ-8B Fire Scout – An unmanned helicopter introduced in 2006. Its main rotor is powered by a Rolls-Royce 250-C20W turboshaft engine, enabling 8-hour flights with a 77 kg payload. Lessons learned from this program led to the development of the larger MQ-8C, powered by a Rolls-Royce 250-C47 B engine. Between 2009 and 2023, the U.S. Navy acquired 30 MQ-8B units and 38 MQ-8C units [15, 40].

Fig. 14. Pratt & Whitney Canada PW207D [41]

– S-70UAS U-Hawk – An unmanned variant of the UH-60L Black Hawk transport helicopter developed by Lockheed Martin. Power is provided by two General Electric T700-GE-701C turboshaft engines, as in the manned version. The cockpit was replaced with cargo space and a loading ramp, increasing usable cargo volume by 25% and simplifying loading operations. Prototype flights are scheduled for 2026 [50, 51].

3.9. Turbofan engines

A turbofan engine is a type of gas turbine engine in which a large fan at the inlet generates a substantial airflow that bypasses the engine core. This configuration enables higher propulsive efficiency and greater thrust at subsonic speeds compared with classical turbojet engines. The high bypass ratio reduces specific fuel consumption and noise levels, which are particularly advantageous for long-endurance, long-range UAV missions. In addition, the reduced acoustic and thermal signatures improve survivability by reducing detectability.

Turbofan engines are primarily employed in larger, technologically advanced UAV platforms where aerodynamic performance, range, and high-altitude capability are key design requirements. However, their structural complexity, relatively high mass, and large physical dimensions generally preclude their application in small UAVs [72, 84]. UAVs powered by turbofan engines are predominantly represented by MALE- and HALE-class platforms:

– MQ-20 Avenger – A U.S. multi-role MALE-class UAV developed by General Atomics as an evolution of the MQ-1 Predator, with its maiden flight in 2009. The airframe features a flattened, blended configuration that enhances stealth characteristics. Propulsion is provided by a Pratt & Whitney Canada PW545B turbofan engine generating 21.4 kN of thrust with a bypass ratio of 3.8. Internal fuel tanks accommodate approximately 3500 kg of fuel, enabling endurance of more than 18 hours at altitudes up to 50,000 ft. The maximum speed is 740 km/h, with a cruise speed of approximately 650 km/h. In 2016, the extended-range MQ-20 ER variant conducted its first flight, featuring increased wingspan and enlarged fuel tanks, which extended endurance to approximately 23 hours [33, 34, 35].
– RQ-4 Global Hawk (Fig. 15) – A HALE-class strategic reconnaissance UAV introduced in 2003 by Northrop Grumman Corporation. The primary design objective was to create an unmanned platform capable of persistent, multi-sensor strategic surveillance. A Rolls-Royce AE 3007H turbofan engine (Fig. 16) producing 34 kN of thrust accelerates the 14-ton air vehicle to a maximum speed of 629 km/h. At a cruise speed of 570 km/h and an altitude of 65,000 ft, the 7800 kg fuel load supports missions exceeding 34 hours and a range of approximately 22,800 km, making the RQ-4 a unique solution on a global scale. Its reconnaissance capability is enabled by an onboard sensor suite including electro-optical and infrared cameras, an AESA radar, and a ground moving target indicator (GMTI) [10, 58, 61, 63, 68, 76].

Fig. 15. RQ-4 Global Hawk [61]

– Bayraktar Kızılelma – An unmanned combat aircraft developed in 2022 by the Turkish company Baykar. The airframe incorporates stealth technologies, while propulsion is provided by an Ivchenko-Progress turbofan engine. The Kızılelma-A variant is powered by the AI-25TLT engine delivering 16.9 kN of thrust, whereas the Kızılelma-B variant uses the AI-322F engine generating 24.5 kN. Due to the mission profile envisioned for this UAV, high speed and low observability were prioritized at the expense of endurance, which is approximately 3 hours. A key advantage is the maximum speed of up to 1100 km/h. Two internal hardpoints and six external wing stations allow the carriage of up to 1500 kg of ordnance [14, 20, 46].

Fig. 16. Rolls-Royce AE 3007H [68]

4. Conclusions

This article provides a comprehensive review of the development and current applications of combustion-based propulsion systems in unmanned aerial vehicles (UAVs), highlighting that engine selection remains a key factor shaping mission profiles, including endurance, range, operational altitude, speed, and payload capacity. Against the backdrop of historical evolution from early UAVs with simple piston engines, through the era of flow engines used in high-speed systems, to the contemporary diversification of propulsion solutions, it is evident that combustion engines continue to play a critical role, particularly in medium and large UAV classes, where liquid fuels provide an energy advantage over batteries.

The conducted review demonstrates that no single propulsion architecture is universally optimal for all UAV categories and mission profiles. Instead, propulsion system selection is strongly dependent on operational requirements, including endurance, flight speed, payload capacity, altitude, detectability, and logistical constraints.

Two-stroke spark-ignition engines remain particularly suitable for lightweight tactical UAVs due to their high power-to-weight ratio, mechanical simplicity, and low acquisition cost. However, their relatively high specific fuel consumption, elevated acoustic signature, and reduced operational efficiency limit their applicability in long-endurance missions.

Four-stroke spark-ignition engines currently represent one of the most balanced propulsion solutions for medium-class and MALE UAVs, offering favorable cruise efficiency, improved reliability, and stable long-duration operation. Compression-ignition and heavy-fuel engines offer additional operational advantages, including lower fuel consumption and standardized fuel in military logistics, though their implementation requires advanced fuel injection systems, turbocharging, and sophisticated thermal management.

Turbine propulsion systems dominate high-speed and high-altitude UAV applications. Turbojet engines are primarily used in strike UAVs and target drones where speed and simplicity are prioritized over endurance. Turbofan and turboprop engines, in turn, enable long-endurance HALE and MALE operations while maintaining relatively high cruise efficiency and operational ceilings.

Rotary piston engines occupy an important niche in medium tactical UAVs due to their compact size, low vibration, and favorable power density. At the same time, pulsejet propulsion remains limited to expendable, low-cost systems due to poor fuel efficiency and a high acoustic signature.

Table 1 summarizes the key characteristics, advantages, and operational limitations of the major propulsion system categories used in UAVs.

Table 1. Comparison of engine characteristics

Engine type	Typical UAV Class	Main advantages	Main limitations
Two-stroke SI	Small tactical UAVs	Low mass, simplicity, low cost	High fuel consumption, noise, emissions
Four-stroke SI	Tactical / MALE UAVs	Reliability, stable operation	Higher mass and complexity
Compression-ignition (HFE)	MALE / HALE UAVs	Fuel economy, JP-8 compatibility	Complex injection and thermal systems
Rotary piston (Wankel)	Medium tactical UAVs	Compact size, low vibration	Lower thermal efficiency
Pulsejet	Expendable UAVs	Extremely simple structure	Very poor efficiency, noise
Turbojet	Strike UAVs	High speed, compactness	High fuel consumption
Turboprop	MALE / HALE UAVs	Excellent cruise efficiency	Lower maximum speed
Turboshaft	Rotary-wing UAVs	Rotorcraft capability	Complex transmission systems
Turbofan	HALE / UCAV platforms	High altitude and endurance	High cost and dimensions

Identified development trends include:

- Continued optimization of piston engine efficiency and reliability for long-endurance flight profiles
- Increasing importance of compatibility with heavy-fuel types in military applications
- Gradual adoption of hybrid solutions, where a combustion engine operates near peak efficiency as an energy source, while the primary propulsion is delivered electrically.

The identified development trends indicate continued efforts to improve the efficiency, reliability, and operational durability of piston propulsion systems for long-endurance UAV missions. Increasing attention is also being directed toward propulsion systems compatible with heavy fuels used in military logistics, particularly JP-8 and Jet-A. Another important direction involves the progressive implementation of hybrid propulsion architectures, in which an internal combustion engine functions primarily as an onboard power generation unit operating near its optimal efficiency range, while thrust is produced by electrically driven propulsion systems.

These developments suggest that future research should increasingly focus on mission-oriented propulsion integration, reduction of acoustic and thermal signatures, enhanced operational resilience under demanding environmental conditions, and lifecycle cost optimization in response to growing operational and environmental expectations.

Future advancements in UAV propulsion are likely to be closely linked to the expansion of hybrid and integrated propulsion concepts combining combustion engines with electric propulsion technologies. Such systems may improve overall energy management efficiency while simultaneously reducing detectability during critical phases of operation through lower acoustic and infrared emissions.

Another significant technological direction is the broader adoption of heavy-fuel propulsion systems aligned with military fuel standardization requirements. At the same time, tightening environmental regulations and sustainability objectives are expected to stimulate further research into sustainable aviation fuels, synthetic fuels, and low-emission combustion strategies applicable to unmanned aircraft.

In addition, the role of intelligent propulsion management systems is expected to increase substantially. Future UAV propulsion architectures will likely incorporate autonomous engine control, artificial intelligence-supported energy management, predictive maintenance systems, and adaptive optimization algorithms designed to improve reliability and operational efficiency. Parallel research efforts will also focus on minimizing the detectability of the propulsion system, increasing robustness in harsh operating environments, and reducing long-term operational costs.

Consequently, future investigations should address not only improvements in propulsion efficiency but also broader issues related to mission integration, autonomy, survivability, operational flexibility, and the sustainability of UAV propulsion systems.

Nomenclature

CI	compression ignition
SI	spark ignition
UAV	unmanned aerial vehicle
ABC	British engine manufacturer
AESA	Active Electronically Scanned Array
AFIS	Aerodrome Flight Information Service
DC	direct current
EO	electro-optical
GMTI	ground moving target indicator
HALE	high altitude long endurance
HFE	heavy fuel engine
IR	infrared
ISR	intelligence, surveillance and reconnaissance
JP-5	jet propellant 5
JP-8	jet propellant 8
Jet A	aviation turbine fuel
MALE	medium altitude long endurance
MTOM	maximum take-off mass
RFC	Royal Flying Corps
UAV	unmanned aerial vehicle
UEL	UAV Engines Ltd.
VTOL	vertical take-off and landing

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